PHYSICS-BASED MODELING OF HIGH-FREQUENCY GROUND MOTIONS AND PROBABILISTIC SEISMIC HAZARD ANALYSIS

Allocation: NSF PRAC/6,600 Kish
P. Philip J. Maechling
Co-Pi: Yifeng Cui, Kam Bak Olsen, Ricardo Taborda

1University of Southern California
2San Diego Supercomputer Center
3San Diego State University
4University of Memphis
5Carnegie Mellon University
63San Diego State University
7University of California, San Diego
8University of Southern California
9Universidad EAFIT, Medellin, Colombia
10Colubmia University

EXECUTIVE SUMMARY

A research collaboration, led by the Southern California Earthquake Center (SCEC), which includes earth scientists, engineers, and computer scientists, used Blue Waters to run physics-based earthquake simulations that improve our understanding of earthquake processes and their effects on seismic hazard. SCEC’s earthquake system science research program develops detailed earth models and high-performance computing software needed to perform realistic, physics-based earthquake simulations and motion simulations. This past year, the SCEC team used NCES Blue Waters to develop more accurate and scalable computational models of earthquakes and to calculate the first physics-based probabilistic ground motion forecasts for Central California.

RESEARCH CHALLENGE

Probabilistic Seismic Hazard Analysis (PSHA) [1] is the scientific framework for many seismic and risk-based engineering and social applications, including performance-based design, seismic retrofitting, resilience engineering, insurance-rate setting, emergency response, and public education. The U.S. Geological Survey (USGS) currently uses empirical PSHA to promote seismic safety engineering and disaster preparedness across the United States, including California. SCEC's research goal is to develop physics-based seismic hazard models for California and elsewhere that are more accurate than the empirical USGS National Seismic Hazard Map Project [2] standard models. Our long-term goal is to extend physics-based PSHA across the full bandwidth needed for seismic building codes and other purposes.

METHODS & CODES

This year, SCEC researchers added improved physics into our wave propagation software and improved our software's performance on CPUs (central processing units) and GPUs (graphics processing units). For high-frequency ground motion simulations, our codes must model frequency-dependent attenuation [3], free-surface topography [4], and nonlinear yielding effects [5]. With improved codes and support through the Blue Waters PAID program, we performed the first 4-Hz nonlinear magnitude 7.7 earthquake simulation using 4,200 GPUs on Blue Waters [6], using a highly optimized implementation of a nonlinear computational method developed by SCEC researchers. We continued to validate our software by simulating well-recorded historic California earthquakes and comparing our simulations against the recorded ground motions [7].

Also this year, we used Blue Waters to perform CyberShake Study 17.3. This study applied the CyberShake [8] PSHA computational method to Central California for the first time. Study 17.3 calculated two seismic hazard models for Central California one using a traditional 1D seismic velocity model and the other using a more accurate 3D velocity model, with results shown in Fig. 1. Results using the 3D velocity model show ground motion levels in the California Central Valley that are markedly lower than the levels produced from the standard ground motion prediction equations (GMPEs) currently in widespread use by earthquake engineers. This is in marked contrast to our results in Southern California, where CyberShake predicts stronger shaking than the GMPEs in the deep, low-velocity sedimentary basins. The differences are related to the lateral extent of the basins, which govern their resonance frequencies and amplitudes. These results provide new evidence that CyberShake's physics-based approach can substantially improve our estimates of strong ground shaking.

We are preparing selected research codes to run efficiently on next-generation supercomputers. We have improved the performance of our wave propagation and Strain Green Tensor codes on next-generation GPUs and Xeon Phi systems [9]. To scale up the I/O performance of our software along with our improved compute performance, we optimized I/O performance of our anelastic wave propagation (AWP) software by increasing our use of third-party HPC (high-performance computing) I/O libraries including ADIOS, HDF5, and PnetCDF.

RESULTS & IMPACT

CyberShake simulations for Southern California are under review as inputs to a new Los Angeles urban seismic hazard map under development by the USGS. The SCEC committee for Utilization of Ground Motion Simulations (UGMS) is working within the framework of the Building Seismic Safety Council activities to develop long-period, simulation-based, spectral-response acceleration maps for the Los Angeles region. Our CyberShake hazard maps are under consideration for inclusion in the National Earthquake Hazards Reduction Program, the American Society of Civil Engineers 7-10 Seismic Provisions, and for the Los Angeles City building codes. The UGMS group is using CyberShake simulations to quantify the effects of sedimentary basins and other 3D crustal structures on seismic hazard information. The SCEC committee for Computational Mechanics, The spectral cell method in nonlinear earthquake modeling.

PUBLICATIONS AND DATA SETS

Taborda, R., N. Khoshevina, S. Azzizadeh-Roodpish, and M. Huda, Influence of the source, seismic velocity, and attenuation models on the validation of ground motion simulations. Poster presentation at World Conference on Earthquake Engineering (Santiago, Chile, January 9–13, 2017), number 4574.